Wireless Physiological and Environmental Monitoring

Operational Field Assessment Report

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The images included herein were provided by DHS S&T, NUSTL and Physical Optics Corporation.

FOREWORD

The First Responder Technologies Division (R-Tech) is part of the U.S. Department of Homeland Security (DHS) Science and Technology Directorate's (S&T's) First Responders Group (FRG). R-Tech works closely with the nation's emergency response community to identify and prioritize mission capability gaps, and to facilitate the rapid development of critical solutions to address responders' everyday technology needs.

R-Tech gathers input from local, tribal, territorial, state and federal first responders, and engages them in all stages of research and development—from building prototypes to operational testing to transitioning tools that enhance safety and performance in the field—with the goal of advancing technologies that address mission capability gaps in a rapid time frame, and then promoting quick transition of these technologies to the commercial marketplace for use by the nation's first responder community.

As R-Tech projects near completion, the National Urban Security Technology Laboratory (NUSTL) conducts an operational field assessment (OFA) of the technology's capabilities and operational suitability to verify and document that project goals were achieved. R-Tech's OFA reports are posted on the First Responder Communities of Practice website — a professional networking, collaboration and communication platform created by DHS S&T to support improved collaboration and information sharing amongst the nation's first responders. This vetted community of members focuses on emergency preparedness, response, recovery and other homeland security issues. To request an account, complete the online form on communities.firstresponder.gov/web/guest/home.

Visit the R-Tech website at www.dhs.gov/science-and-technology/first-responder-technologies for information on other R-Tech projects.

Visit the NUSTL website at www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory for information on other NUSTL projects.

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EXECUTIVE SUMMARY

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) National Urban Security Technology Laboratory (NUSTL) conducted an operational field assessment (OFA) of the Wireless Physiological and Environmental Monitoring (WiPEM) system on July 28, 2017, at Torrance Fire Station #2 in Torrance, California. Six firefighters from the Torrance Fire Department served as evaluators to assess the current prototype of the WiPEM system.

WiPEM is a wireless system developed by Physical Optics Corporation to address a technology gap for wireless physiological, environmental and equipment monitoring sensors in extreme environments. The WiPEM system consists of an array of sensors that collect the wearer's vital sign data: heart rate, respiration rate, skin temperature and blood oxygenation level. The WiPEM physiological sensors are designed to be integrated into a self-contained breathing apparatus (SCBA) face mask. Vital sign data is transmitted from the WiPEM sensors via Bluetooth to the wearer's Android phone, which transfers the data to the incident commander's Android phone, allowing the incident commander to remotely monitor the wearer via a graphical user interface (GUI). In addition to vital sign data, the WiPEM system also transmits air pressure and time remaining in the wearer's SCBA air tank and the presence of external environmental gases detected by a separate multigas meter. The WiPEM's software calculates the wearer's physical strain index, which is determined by the wearer's skin temperature and heart rate, and displays results as a color-coded indicator to warn the incident commander that the wearer is near exhaustion or already exhausted.

During the OFA, three of six evaluators donned an SCBA mask equipped with the WiPEM sensors, then performed several physical activities that mimicked common tasks encountered in firefighting operations. Other evaluators, serving as the incident commander, viewed the wearer's vital sign data through the GUI on an Android device.

The evaluators found the WiPEM system did not successfully capture or transmit vital sign data or calculate the wearer's physical strain index, and though the SCBA air tank pressure information was transmitted, air time remaining was inaccurate. The evaluators believed the WiPEM's GUI contained too many data points for a single firefighter to view and analyze, and the GUI would overwhelm an incident commander during stressful operations. Additionally, they found the WiPEM system's capability to monitor vital sign data for a single firefighter at a time is a significant limitation for the technology's operational functionality. Since firefighting operations typically require multiple firefighters, for the WiPEM system to be useful to an incident commander, it would need to be able to provide vital sign data for all personnel involved in the response in a simple and intuitive manner, and hence would require the incident commander GUI to be redesigned.

The inaccuracy of the remaining air time reading was a particular concern to evaluators. They noted that an incident commander would not pull a firefighter from response operations based on vital sign data alone. The remaining air time is the only data point that would cause an incident commander to remove a firefighter from response operations according to the evaluators.

Regarding the WiPEM system's design, the evaluators noted that it would not pass the firefighter mask fit test because the sensor could impede the mask being flush with the skin. Additionally, two of three evaluators who donned the prototype noticed a sensor wire out of the corner of their right eye. While this did not obstruct their view, the fact that they noticed the wire, in and of itself, would

make the WiPEM system unacceptable for operations. Also, two of the three evaluators had difficulty viewing the GUI in broad daylight, but did not have the same difficulty in low-light conditions.

Lastly, the evaluators recommended the WiPEM system either turn on automatically when firefighters go on-air or that the on/off switch be relocated to the side of the SCBA to make it easier for the firefighter to turn the system on and off.

After assessing the WiPEM system's performance and analyzing the evaluator feedback, NUSTL determined the current prototype system is unacceptable: it cannot be incorporated into firefighter operations without additional development of the sensor array and associated software, and further testing and maturation is required before it can be adopted by firefighters.

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1.0 INTRODUCTION

The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group (FRG) First Responder Technologies Division (R-Tech) awarded contracts, in March 2014 and March 2015, to Physical Optics Corporation to develop the Wireless Physiological and Environmental Monitoring (WiPEM) system with the objective of:

> [Developing] a single wireless device that will monitor [the] physiological and environmental conditions of and surrounding a first responder, and relay [that] information to… incident command.[i]

As an R-Tech project near completion, the DHS S&T FRG National Urban Security Technology Laboratory (NUSTL) conducts an operational field assessment (OFA) to evaluate the technology's performance. On July 28, 2017, NUSTL conducted an OFA of the WiPEM system. During this OFA, six Torrance Fire Department (California) firefighters served as evaluators and engaged in various physical activities while wearing the WiPEM system to evaluate its capabilities and suitability. This report describes the OFA activities performed, the results from those activities and the evaluators' feedback.

1.1 PURPOSE

The purpose of the OFA was to assess the WiPEM system's performance for potential operational use for first responder physiological, environmental and equipment monitoring.

1.2 OBJECTIVE

The objective of the OFA was to assess and obtain evaluator's feedback on the WiPEM system when used during activities that mimic firefighting operational response conditions.

The WiPEM OFA was designed to assess:

- Ease of use, comfort and operational value; and
- System and design requirements.

1.3 REQUIREMENTS

Table 1-1 summarizes the requirements the WiPEM system was expected to achieve and the ways those requirements were assessed during the OFA. Table 1-1 also notes which system requirements were outside the scope of this OFA. Requirements were drawn from the original technical proposal and the WiPEM Phase II Critical Design Review presentation.

[i] (U.S. Department of Homeland Security, 2014) SBIR Pre-solicitation FY14. SBIR Topic Number: H-SB014.1-004. Retrieved from www.fbo.gov

Table 1-1 WiPEM Requirements Matrix

Category	Requirement	Test Method
Sensors	• Measure skin temperature (°F) • Measure heart rate (beats per minute) • Determine blood oxygenation level, also known as pulse oxygenation (%) • Incorporate respiratory rate (breaths per minute [brpm]) into physical strain index to counter possible skewing based on heart rate alone • Add a carbon dioxide (CO_2) sensor inside self-contained breathing apparatus (SCBA) mask to measure responder's physical condition	• Spot test comparison with standard emergency medical technician (EMT) equipment and methods • The CO_2 sensor accuracy was not be tested
Power	• Use AAA battery instead of rechargeable battery • Optimize battery location for different brands of SCBA facemasks (e.g., AVON, Scott, Honeywell and MSA)	Responder inspection and feedback
Ergonomic Design	• Wearable • Lightweight • Easy to implement and maintain • Compact, self-contained • Automatic • Unobtrusive—does not block visual field • Requires no special training or additional work	Responder subjective feedback
Standards	• National Fire Protection Association (NFPA) certification • Intrinsically safe • Resistant to heat, water and dropping/shock • Waterproof for soapy water cleaning	Not tested—outside scope for OFA. An independent standards certification is required to ensure an airtight seal is maintained around the face, no internal outgasing inside mask, etc.

Environmental	• Integrate gas data from a commercially available gas monitor into display for incident command for the following:
	  • Carbon monoxide (parts per million [ppm])
	  • Oxygen (%)
	  • Hydrogen sulfide (ppm)
	  • Lower explosive limit (LEL) (%)
		View output on incident command display

SCBA Air Tank	• Integrate SCBA air tank pressure data • Display air tank time left (minutes)	View output on incident command display
Communication	• Transmit physiological, environmental and equipment data from WiPEM to the designated Android phone via Bluetooth • Transmit data from the wearer's Android phone to the incident commander's Android device via public safety broadband network	• Test under operational conditions • If public safety broadband network is not ready in time for testing, use standard cell phone network. May use Wi-Fi for OFA.
Incident Command Display	• Real time display to incident command • Display on a smartphone, laptop or Android tablet outdoors • Allow incident commander to monitor multiple WiPEM systems simultaneously • Meaningful physical strain index applicable to various individuals	• Responder assessment of display under operational conditions, including various ambient lighting settings • Physical strain index rating will be compared to EMT assessments and users' feedback. False positives will be detected; true positives and false negatives are outside the scope of this OFA.

1.4 Prototype Description

The WiPEM system wirelessly integrates a combination of physiological, environmental and equipment sensors. This includes physiological sensors that determine heart rate, respiration rate, physical strain index, skin temperature and blood oxygenation level. The hand held gas monitor measures oxygen (O_2), hydrogen sulfide (H_2S), carbon monoxide (CO) and lower explosive limit (LEL) levels. The equipment sensor monitors the air tank pressure and time remaining. The vital sign data collected by these sensors is transmitted, via Bluetooth, to the wearer's Android phone, which can also transfer the data over 4G Long Term Evolution (LTE) cellular networks via a private internet server to the incident commander's Android phone, allowing the incident commander to remotely monitor the wearer via a graphical user interface (GUI).

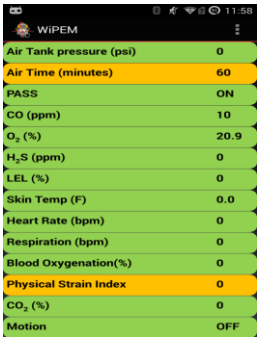

Figure 1-1 Android Phone GUI Display

The WiPEM's software uses the vital sign data to calculate the physical strain index, which is determined by the wearer's skin temperature and heart rate, and displays results as a color-coded indicator to warn the incident commander that the wearer is near exhaustion or already exhausted. The system conveys this warning through three color-coded levels: green (no risk), orange (possible risk) and red (definite risk). When the wearer is at "possible risk," the incident commander should verbally check on the wearer's status. When at the "definite risk," the wearer should exit the hazardous environment.

Figure 1-2 WiPEM Physiological Monitor in SCBA Mask

The WiPEM physiological sensor array is lightweight, weighing 10 grams, and small, with dimensions of 12 x 3 x 160 millimeters. The sensor was designed to be integrated directly onto a self-contained breathing apparatus (SCBA) mask—no sensors are attached to the wearer's body—and no user control is needed during use.

The WiPEM system also integrates additional commercial environmental and equipment sensing hardware, and collects and combines the data through the system's software. The hardware consists of a WiPEM sensor array and Android devices (smartphones or tablets) for the wearer and incident commander. The software monitors and transmits vital sign data, environmental conditions data and remaining air pressure in the air tank, and calculates the wearer's physical strain index.

Figure 1-3 SCBA Air Tank

Multi-gas monitors and SCBA air tanks (cylinders) are standard equipment for firefighters. A Scott Protégé multi-gas monitor measures potential environmental hazards that commonly exist at a fire scene, including oxygen, hydrogen sulfide, carbon monoxide and LEL. A Scott SCBA air tank provides closed-circuit, breathable air in hazardous environments. The WiPEM system integrates output from the sensor array, the multi-gas monitor and the air tank pressure via Bluetooth and displayed on the WiPEM GUI.

The WiPEM system is powered by two non-rechargeable AAA batteries due to the concerns that lithium-ion rechargeable batteries could pose an explosive hazard in extreme environments. The battery life of the sensor array is approximately six to 12 hours depending on reporting frequency, skin tone and blood profusion level. The Protégé multi-gas meter has a rechargeable battery that lasts approximately 18 hours.

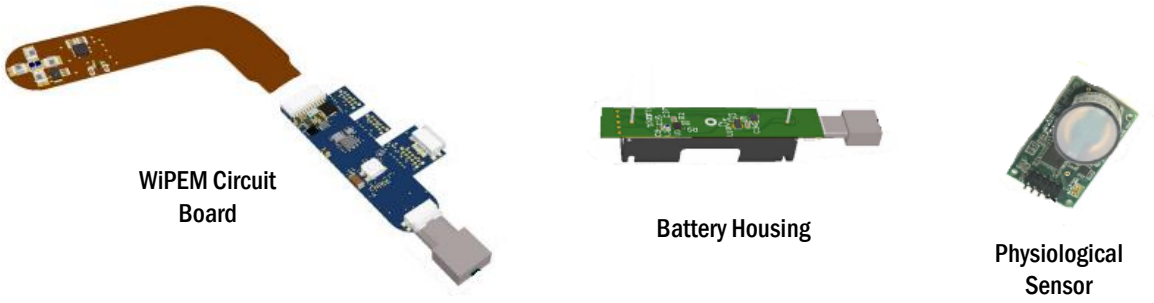

Figure 1-4 WiPEM Physiological Monitor Composition

2.0 OPERATIONAL FIELD ASSESSMENT DESIGN

2.1 Event Design

The OFA was a one-day event in which six evaluators used and provided feedback on the WiPEM system. The evaluators used the WiPEM system in simulated scenarios based on firefighting response operations. The venue was Torrance Fire Station #2 in Torrance, California. Operational scenarios were set up at an outdoor training area. Group discussions were held in a nearby trailer. The Torrance Fire Department provided the props and structures for the operational scenario test stations. The OFA consisted of seven test stations. Five of the stations covered different activities associated with firefighting response operations, one station was for measuring baseline physiological signs and the other was a simulated command station where evaluators viewed the WiPEM GUI. These stations are summarized in Table 2-1[ii]. Firefighters spent 2-3 minutes at each of the five activity stations referred to as "circuit."

Table 2-1 Summary of OFA Activities

Station	Location	Task
Stair Climb	3-story building	Climb three flights of stairs with a bundled hose
Hose Drag	Parking area	Drag a hose approximately 50 yards
Equipment Carry	Parking area	Pick up a hose bundle from a table and carry it back and forth to another table
Ladder Raise and Extension	Pulley structure	Raise and lower a hose bundle by rope attached to a pulley
Forced Entry	Parking area	Repeatedly swing an axe at a log
Vital Sign Baseline	Parking area	Measure heart rate, respiration rate, skin temperature and blood oxygenation level using standard EMT equipment
Incident	Parking area	Observe vital sign data reported by WiPEM displayed on an Android phone

[ii] Full details on the event design are described in the WiPEM OFA Test Plan (U.S. Department of Homeland Security's National Urban Security Technology Laboratory, July 2017).

2.2 Participants

Table 2-2 lists the OFA participants.

Table 2-2 Participants

Role	Organization
Evaluators 1-6	Torrance Fire Department
Program Manager	DHS S&T R-Tech
OFA Director and Data Collectors	DHS S&T NUSTL
Technology Developer	Physical Optics Corporation
Observers	DHS S&T R-Tech
Photographer/Videographer	S&T Communications and Outreach

2.3 Scope and Limitations

The OFA was designed to include three portions: classroom training, performance of operational scenarios and a post-OFA debrief and questionnaire. Participants were given the opportunity to provide verbal feedback during each portion of the assessment; that feedback was captured by NUSTL and is presented in Section 3 of this report.

A single prototype was available during the OFA, thus the evaluators took turns performing activities—baselining vital signs before and after those activities—and viewing the WiPEM's GUI on an Android smartphone.

Figure 2-1 WiPEM Inside SCBA Mask

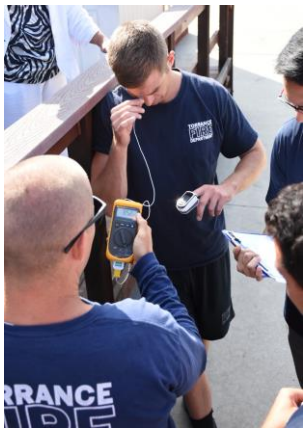

Figure 2-2 Baselining Vital Signs

Figure 2-3 Donning Full PPE

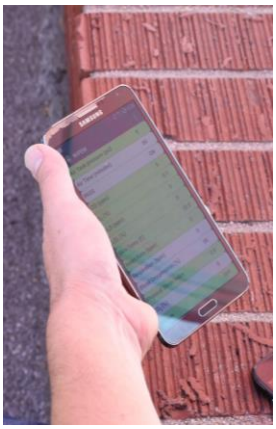

Figure 2-4 Viewing Data on GUI

During the performance of the operational scenarios, three evaluators wore personal protective equipment (PPE) that included: turnout gear, boots, gloves, an SCBA mask and a helmet. Each evaluator wore a Scott SCBA mask; therefore, the OFA did not evaluate whether the WiPEM system could be installed and used on any other brand of SCBA mask. Before and after each evaluator performed operational scenarios, another evaluator captured their vital sign data as a benchmark for comparison to the WiPEM physiological measurements.

As each evaluator completed the test station circuit, another evaluator served as the incident commander and monitored the vital sign data on WiPEM's GUI display. After an evaluator completed the test station circuit, their baseline vital signs were measured twice, before and after they doffed their PPE. They then completed a written questionnaire. The evaluator serving as the incident commander also completed a written questionnaire after cessation of the test station circuit.

2.4 Deviation from the Assessment Plan

Due to unforeseen problems with the prototype WiPEM system and practical considerations at the venue site, the following changes were made to the planned OFA activities.

- SCBA installation and battery change procedures were not evaluated. Physical Optics Corporation demonstrated these procedures, instead of allowing the evaluators to execute them, due to their concerns that the single prototype was too fragile to endure repeated handling. Evaluators were, therefore, unable to assess these requirements and could not complete survey questions related to their ability to perform these tasks.
- Data was sent over a standard cellular network rather than the public safety long term evolution network. This was because the public safety long term evolution network is not operational in the Los Angeles County area. The WiPEM system used two commercial Samsung Galaxy Note II smartphones communicating over the standard LTE cellular network. As a result, the Motorola LEX 700, which was called for in the test plan, was not needed.
- Blood oxygenation readings were not recorded. Physical Optics Corporation stated at the outset of the day of the OFA that the blood oxygenation sensor was not working. Therefore, baseline blood oxygenation readings were not recorded using EMT equipment. After a troubleshooting session, the WiPEM blood oxygenation sensor momentarily began working, at which point a single blood oxygenation reading was recorded and sent to the GUI for the third evaluator. However, once the third evaluator initiated the circuit, all sensors stopped working, including the blood oxygenation sensor.
- Integration with the Scott Protégé multi-gas monitor was not evaluated. The Scott Protégé multi-gas monitor provided by Physical Optics Corporation was out of calibration and would not properly report oxygen levels.
- OFA was suspended due to WiPEM sensor failure. The WiPEM physiological sensors stopped sending vital sign data approximately seven minutes into the first evaluator's run through the test station circuit. Physical Optics Corporation began troubleshooting the hardware, and after a few minutes delay, the second evaluator began the circuit; however, the WiPEM stopped sending all wireless data immediately thereafter. After two hours of troubleshooting, the third evaluator began the test station circuit, but the WiPEM system was still not functional. The OFA was terminated at this point.
- Search and rescue scenario was not conducted. This scenario was found to be impractical to simulate in the available space at the venue. The omission of the planned search and rescue scenario constituted a minor change that would not significantly affect the OFA, as the remaining activities offered sufficient opportunities to simulate operational conditions. However, the fragility of the prototype and system malfunctions significantly affected the evaluators' ability to assess the system.

3.0 RESULTS

This section contains the OFA results. Section 3.1 includes results from the evaluators' surveys. Section 3.2 includes analyses from the debrief session held at the conclusion of the assessment. Section 3.3 is a requirements assessment based on the data collected during the OFA, as well as data and feedback derived from the surveys and debrief session. The conclusions are found in Section 3.4, which compiles the major findings from each results section.

Table 3-1 Survey Results

Survey Statement	Evaluator					
	1	2	3	4	5	6
Classroom Training						
1. Battery Replacement	N/A	N/A	N/A	N/A	N/A	N/A
2. Donning/Doffing	N/A	N/A	N/A	N/A	N/A	N/A
3. Weight	N/A	N/A	N/A	N/A	N/A	N/A
4. Comfort Level	N/A	N/A	N/A	N/A	N/A	N/A
5. Field of View	N/A	N/A	N/A	N/A	N/A	N/A
6. Maintenance	N/A	N/A	N/A	N/A	N/A	N/A
Performance of Operational Scenarios						
1. Does Not Restrict Range of Motion	Strongly Agree	Strongly Agree	Strongly Agree	N/A	N/A	N/A
2. Comfort Level Acceptable	Strongly Agree	Strongly Agree	Strongly Agree	N/A	N/A	N/A
3. Field of View Unobstructed	Agree	Strongly Agree	Agree	N/A	N/A	N/A
4. Donning/Doffing Compared to Existing Equipment	Strongly Agree	Strongly Agree	Strongly Agree	N/A	N/A	N/A
Observing the Graphical User Interface						
1. Simple to Understand	N/A	N/A	Strongly Agree	Agree	Agree	N/A
2. Easy Menu Navigation	N/A	N/A	Strongly Agree	Agree	Agree	N/A
3. Visible in Broad Daylight	N/A	N/A	Strongly Agree	Disagree	Disagree	N/A
4. Visible in Low-light	N/A	N/A	Strongly Agree	Strongly Agree	Strongly Agree	N/A
5. WiPEM Software Ran Smoothly	N/A	N/A	Strongly Disagree	Strongly Disagree	Strongly Disagree	N/A
6. WiPEM Information is Useful	N/A	N/A	Strongly Agree	Agree	Strongly Disagree	N/A

N/A = Not Applicable (not evaluated) Color-Coded Cells = Strongly Agree | Agree | Disagree | Strongly Disagree

3.1 Survey

The evaluators' survey results are shown in Table 3-1 Survey Results, which includes a row for each of the survey statements and a column for each evaluator. A color-coded format is used: a dark green square indicates the evaluator strongly agreed with the survey statement; light green indicates the evaluator agreed with the survey statement; red indicates the evaluator disagreed; and dark red indicates strong disagreement with the survey statement. "N/A" indicates the evaluator did not perform the activity needed to respond to the survey statement

As discussed in Section 2.4, the WiPEM system was not ready to be handled by evaluators at the outset of the OFA. As a result, the classroom training portion of the OFA was cancelled. The OFA was then terminated after the third evaluator completed the test station circuit because the WiPEM system was no longer functioning.

Figure 3-1 WiPEM Wire
The WiPEM wire is visible above the evaluator's right eye.

As can be seen by the survey results presented in Table 3-1, the evaluators indicated that while wearing the WiPEM system, their range of motion was unimpeded, their comfort level was unchanged, their field of view was unobstructed, and there was no difference in donning and doffing the SCBA with or without WiPEM installed. While the evaluators agreed their field of view was unobstructed, two of evaluators could see the WiPEM wire out of the corner of their right eye (Figure 3-1). One of these evaluators commented that the wire would have to be completely out of sight before they could consider using WiPEM during response operations.

When observing the WiPEM's GUI, evaluators agreed that it was not difficult to understand; however, they believed there was too much information on the screen, and that it needed to be simplified by reducing the quantity of information on the screen. (Figure 3-2). They thought there were too many numbers on the screen for an incident commander to properly assess during a response operation. The evaluators agreed that navigating between menus was easy; although, one evaluator recommended inserting a "home" link on the screen to make it easier. All of the evaluators who viewed the GUI agreed that it was easy to view in low-light conditions; however, two of the three firefighters found it very difficult to view the screen in daylight conditions.

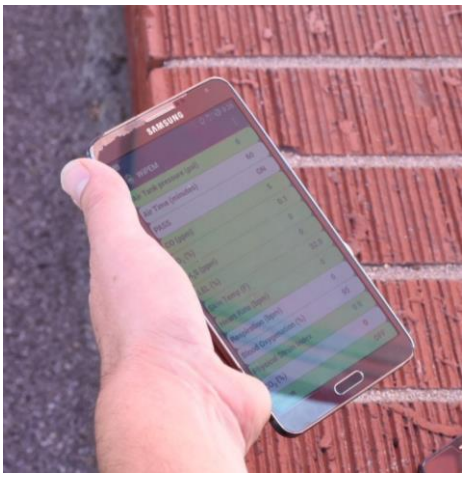

Figure 3-2 WiPEM GUI
An evaluator views the WiPEM GUI during the OFA.

Vital sign data reported by the WiPEM system is shown in Tables 3-2, 3-3 and 3-4. In each table, vital sign data measured using standard EMT equipment are shown in bold font for comparison with WiPEM readings. These data points measured as a baseline before the circuit are shown in the first row, while the after-circuit data are shown in the last two rows. The after-circuit vitals were taken immediately after activities were completed while the evaluator was still wearing the SCBA, and again after the SCBA was doffed. In the tables, "0" indicates the WiPEM system reported a zero (or blank); "N/A" means not applicable where no reading was expected from the WiPEM or EMT measurements. The system transmitted air tank pressure information, but the air time data was inaccurate, as the air time measurement (60 minutes) remained unchanged throughout the entire circuit.

As shown in Table 3-2, for the first evaluator, the WiPEM system was initially able to provide skin temperature (89.6°F) and heart rate (56-57 beats per minute [bpm]), but soon began recording inaccurate values. For example, at three minutes into the activities, the system recorded that the evaluator's skin temperature had dropped to 32°F and the heart rate remained nearly unchanged despite three minutes of rigorous activity. At six minutes, these measurements remained unchanged. At nine minutes, the system was no longer providing data.

Table 3-2 WiPEM Readings for Evaluator 1

Activity	Skin Temperature	Heart Rate	Physical Strain Index	Blood Oxygen	Air Pressure	Air Time
EMT Baseline Vitals	**89-90**	**50-54**	N/A	N/A	N/A	N/A
Initial WiPEM Vitals	89.6	56-57	0	0	3600	60
3 minutes into circuit	32	53	0	0	2816	60
6 minutes into circuit	32	53	0	0	2296	60
9 minutes into circuit	0	0	0	0	1756	60
12 minutes into circuit	0	0	0	0	1242	60
EMT immediately after circuit while wearing SCBA	**90-95**	**156**	N/A	N/A	N/A	N/A
EMT after circuit after SCBA doffed (~1.5 minutes after circuit)	**89-90**	**50-54**	N/A	N/A	N/A	N/A

Notes:
Skin Temperature = degrees Fahrenheit (°F)
Heart Rate = beats per minute (bpm)
Physical Strain Index = determined by skin temperature and heart rate
Blood Oxygen = percentage level (%)
Air Pressure = pounds per square inch
Air Time = minutes
N/A = not applicable

As shown in Table 3-3, no physiological data was reported for the second evaluator as the WiPEM system ceased functioning immediately upon the evaluator donning the SCBA.

Table 3-3 WiPEM Readings for Evaluator 2

Activity	Skin Temperature	Heart Rate	Physical Strain Index	Blood Oxygen	Air Pressure	Air Time
EMT Baseline Vitals	**88-90.5**	**76**	N/A	N/A	N/A	N/A
Initial WiPEM Vitals	0	0	0	0	4152	60
3 minutes after Circuit	0	0	0	0	3346	60
6 minutes after Circuit	0	0	0	0	2536	60
9 minutes after Circuit	0	0	0	0	1922	60
12 minutes after Circuit	0	0	0	0	1356	60
EMT immedately after circuit while wearing SCBA	**92-97**	**168**	N/A	N/A	N/A	N/A
EMT after circuit after SCBA doffed (~1.5 minutes after circuit)	**94-96**	**144**	N/A	N/A	N/A	N/A

Notes:
Skin Temperature = degrees Fahrenheit (°F)
Heart Rate = beats per minute (bpm)
Physical Strain Index = determined by skin temperature and heart rate
Blood Oxygen = percentage level (%)
Air Pressure = pounds per square inch
Air Time = minutes
N/A = not applicable

For the third evaluator, the WiPEM system was able to initially record skin temperature (92.3°F), heart rate (82 bpm) and blood oxygenation (95%), which were similar to the baseline measurements; however, immediately upon beginning the test station circuit, the WiPEM system stopped functioning and no measurements were recorded.

Table 3-4 WiPEM Readings for Evaluator 3

Activity	Skin Temperature	Heart Rate	Physical Strain Index	Blood Oxygen	Air Pressure	Air Time
Baseline Vitals	**92.3**	**77-78**	N/A	N/A	N/A	N/A
Initial WiPEM Vitals	92.3	82	0	95%	4494	60
3 Minutes after Circuit	0	0	0	0	3544	60
6 Minutes after Circuit	0	0	0	0	2676	60
9 Minutes after Circuit	0	0	0	0	1970	60
12 Minutes after Circuit	0	0	0	0	1252	60
EMT immedately after circuit while wearing SCBA	**97.7**	**156**	N/A	N/A	N/A	N/A
EMT after circuit after SCBA doffed (~1.5 minutes after circuit)	**92**	**136**	N/A	N/A	N/A	N/A

Notes:
Skin Temperature = degrees Fahrenheit (°F)
Heart Rate = beats per minute (bpm)
Physical Strain Index = determined by skin temperature and heart rate
Blood Oxygen = percentage level (%)
Air Pressure = pounds per square inch
Air Time = minutes
N/A = not applicable

Based on these observations and readings, the evaluators all reported that the WiPEM system did not accurately or consistently provide vital sign data (skin temperature, heart rate, respiration rate and blood oxygenation) or calculate the physical strain index. Additionally, the system transmitted air tank pressure information, but the air time data was inaccurate, as the air time measurement (60 minutes) remained unchanged throughout the entire circuit.

Furthermore, even if the WiPEM system had been able to provide accurate and consistent vital sign data, the evaluators disagreed as to whether that information would be usable. One evaluator believed the vital sign data could be useful for an incident commander to gauge a firefighter's level of exhaustion; however, two evaluators believed there were "*simply too many numbers on the screen*" to be of any value to an incident commander. According to one evaluator, during a response, an incident commander will view multiple data screens from various equipment (unrelated to the WiPEM system) to absorb multiple data points simultaneously, and therefore would be unable to follow the multitude of numbers on the WiPEM GUI. One evaluator recommended providing the most critical or imminently critical information on the GUI, perhaps just the physical strain index.

Lastly, one evaluator noted that an incident commander oversees multiple personnel during an incident, anywhere between 10 and 50. As such, an incident commander would need to be able to evaluate the vital sign data of all personnel involved in a response and not just the data for a single firefighter. The firefighters proposed the idea of having the ability to easily switch screens between firefighters to monitor key vital sign data for different firefighters.

3.2 Post Operational Scenario Debrief

During the post operational scenario debrief session, the evaluators discussed their experiences during the operational scenarios, expanded on their survey feedback and discussed the overall system performance. Discussions centered on the following topics:

- Vital sign data—Inability to provide vital sign data or a physical strain index;
- Air tank levels—Inability to provide accurate air time remaining;
- Data Points—Excessive data points on the GUI;
- Multiple firefighter assessment—Inability to provide data on multiple firefighters simultaneously; and
- On/Off Switch—The WiPEM system should turn on automatically or turn on more easily.

The WiPEM system's inability to provide vital sign data and calculate the physical strain index as described in the project preliminary design review was discussed at length. The evaluators agreed it would have been useful to have an additional prototype available for the OFA; in the event that one failed, another could have been assessed.

The evaluators agreed that if the WiPEM system had been able to provide vital sign data, such data would only be useful for an incident commander in assessing their firefighters if that data was reliable, easy to view and analyze, and available in real-time. One evaluator emphasized the importance of data reliability, stating, "*The single time WiPEM is wrong, and a firefighter is pulled from an incident in lieu of continuing his or her life-saving duties, it would never be used again.*"

This evaluator went on to say, "*You are not going to get a firefighter off of a task unless [they] run out of air*." The evaluators then noted that the single most useful data point that a firefighter and incident commander would be interested in is the air remaining in the firefighter's air tank. One evaluator stated, "*When a firefighter is aware that [their] air tank level is low, a firefighter can utilize certain techniques to conserve air tank levels, e.g., skip breathing*." The WiPEM system reported air pressure remaining in the air tank during the OFA, but did not accurately report air time remaining.

The evaluators agreed that the long list of data points on the GUI would overwhelm an incident commander during a response operation. "*There are too many fields with too many numbers*," said one evaluator. Two of the WiPEM system's stated capabilities, the stoplight function (three color-coded levels: green [no risk], orange [possible risk] and red [definite risk]) and the physical strain index, would provide the incident commander with the most relevant information in the simplest way; however, neither of these features were functional during the OFA.

During the debrief, the evaluators reiterated that a single response operation could require up to 50 firefighters, and an incident commander would need to monitor the vital sign data for all firefighters involved in the response, not just those of a single firefighter. As such, evaluators recommended incorporating a feature for viewing multiple firefighters' vital sign data simultaneously into future WiPEM models.

Lastly, the evaluators discussed how the location of the WiPEM system's on/off switch on the inside of the mask would be difficult for firefighters to use. Evaluators believed firefighters would likely either forget to turn it on/off or they would purposely not turn it on/off to save time. One evaluator noted that as soon as a firefighter receives the order to enter a response scene, they immediately don their gear without hesitation. Another evaluator suggested that the WiPEM system turn on automatically when their air tank is enabled, or have the switch located on the outside of the face mask to make it easier to switch on/off.

3.3 Requirements Assessment

NUSTL assessed the WiPEM system against the requirements established by DHS S&T FRG R-Tech and set forth in the WiPEM OFA Plan. These requirements are organized in eight categories:

1. Sensors
2. Power
3. Ergonomic design
4. Standards compliance
5. Environmental monitoring
6. Air tank monitoring
7. Communication
8. Incident command display

To assess the WiPEM system's performance against these requirements, NUSTL analyzed the data collected during assessment activities and the evaluators' oral and written feedback provided during assessment activities and debrief session and surveys. The assessment results are detailed in the following Table 3-5.

Table 3-5 Assessment Results

Category	Requirement	Assessment Method	Results
Sensors	• Measure skin temperature (°F) • Measure heart rate (beats per minute [bpm]) • Determine pulse oxygenation (%) • Incorporate respiratory rate (breaths per minute [brpm]) into physical strain index in order to counter possible skewing based on heart rate alone • Add a carbon dioxide (CO_2) sensor inside SCBA mask to measure responders' physical condition	• Spot test comparison with standard emergency medical technician (EMT) equipment and methods • The CO_2 sensor accuracy will not be tested	• WiPEM could not accurately or consistently measure skin temperature (°F), heart rate (bpm), blood oxygenation level (%) or respiratory rate (brpm) • WiPEM was unable to develop a physical strain index • WiPEM could not incorporate respiratory rate into physical strain index • The CO_2 sensor accuracy was not tested
Power	• Use AAA battery instead of rechargeable battery • Optimize battery location for different brands of SCBA facemasks (e.g., AVON, Scott, Honeywell and MSA)	Responder inspection and feedback	• Responders did not change or inspect battery per the Physical Optics Corporation's instruction that WiPEM can only be changed by Physical Optics Corporation during the OFA • Different brands of SCBA facemasks were not used
Ergonomic Design	• Wearable • Lightweight • Easy to implement and maintain • Compact, self-contained • Automatic • Unobtrusive—does not block visual field • Requires no special training or additional work	Responder subjective feedback	• Evaluators could not feel the sensor when donning the mask; however, they stated that it would not pass the mask "fit" test that requires the mask to be completely flush with the wearer's skin • WiPEM was unobtrusive, it does not block the visual field; however, two of three evaluators noted a sensor wire was visible in the corner of their right eye • WiPEM is not automatic. The sensor switch located inside the SCBA has to be turned on; evaluators recommended having the switch on the outside of the SCBA for easy access, or have WiPEM turn on automatically when they go on-air.

Category	Requirement	Assessment Method	Results
Standards Compliance	• National Fire Protection Association (NFPA) certification • Intrinsically safe • Resistant to heat, water and dropping/shock • Waterproof for soapy water cleaning	Not tested—outside scope for OFA. An independent standards certification is required to ensure an airtight seal is maintained around the face, no internal outgassing inside mask, etc.	• Not tested • POC stated that WiPEM is not waterproof
Environmental Monitoring	Integrate gas data from a commercially available gas monitor into display for incident command for the following: • Carbon monoxide (parts per million [ppm]) • Oxygen (%) • Hydrogen sulfide (ppm) • LEL (%)	View output on incident command display	• Not tested. The Scott Protégé multigas meter supplied by POC with bluetooth technology was out of calibration and did not report accurate data.
SCBA Air Tank Monitoring	• Integrate SCBA air tank pressure data • Display air tank time left (minutes)	View output on incident command display	• WiPEM provided air pressure data, but could not accurately provide air tank time. The air time measurement of 60 minutes remained unchanged throughout the entire OFA, despite after being used 12 minutes at a time during operational scenarios and also when a smaller air tank was used
Communication	• Transmit physiological data from the WiPEM physiological monitor to the designated Android phone via Bluetooth • Transmit data from the Android handheld device of the wearer to the Android device held by the incident commander via public safety broadband network	• Test under operational conditions • If public safety broadband network is not ready in time for testing, use standard cell phone network. May use Wi-Fi for OFA.	• WiPEM could not accurately or consistently transmit physiological data • A public safety broadband device was not used

Category	Requirement	Assessment Method	Results
Incident Command Display	• Real time display to incident command • Display on phone, laptop PC or Android tablet outside • Allow commander to monitor multiple WiPEM systems simultaneously • Meaningful Physical Strain Index applicable to various individuals	• Responder assessment of display under operational conditions, including various ambient lighting settings • Physical strain index rating will be compared to EMT assessments and user feedback. False positives will be detected; true positives and false negatives are outside OFA scope.	• Display was shown on a Android phone, and not on a laptop or tablet • Display can be easily viewed in low-light conditions • Firefighters had difficulties viewing the display while in sunlight • Only one WiPEM was available for testing • WiPEM was unable to provide a physical strain index. The WiPEM GUI does not allow for the monitoring of multiple wearers

3.4 Conclusions

The evaluators' general consensus is that the current prototype WiPEM system is unacceptable: it cannot be incorporated into firefighter operations without additional development of the sensor array and associated software, and further testing is required before it can be adopted by firefighters.

The prototype WiPEM system could not successfully capture or transmit vital sign data, provide accurate air tank time, or calculate a physical strain index for the evaluators. Moreover, even if the WiPEM system could capture vital sign data, the system's GUI display contained too many data points to view and analyze, and would overwhelm an incident commander during stressful operations. The WiPEM system's purported stop-light feature and physical strain index measure could potentially solve this issue, but neither features were functioning during the OFA.

Additionally, as the WiPEM GUI would only be able to monitor vital sign data for a single firefighter at a time, it would not be suitable for firefighting operations. As the evaluators noted, firefighting response operations include multiple firefighters (up to 50 in some cases) and for the system to be useful to an incident commander, it would need to be able to provide vital sign data for all personnel involved in the response operation.

Furthermore, evaluators noted that an incident commander would not pull a firefighter from an incident based on vital sign data alone. The evaluators stated that if the WiPEM system was found to provide inaccurate data to an incident commander during a response operation even once, it would not be used again.

The evaluators unanimously agreed that the single most important data point that an incident commander and firefighter should be aware of is firefighters' remaining air supply. The evaluators believed an incident commander would only pull a firefighter off task based on the data point for

their remaining air supply. Though the WiPEM system reported air tank pressure, it failed to accurately report air time remaining during the OFA.

Regarding the WiPEM system's design, evaluators could not feel the sensor when donning, doffing or wearing the SCBA; however, they noted that it would not pass the mask fit test because the sensor could impede the mask being flush with the skin. (Occupational Safety and Health Administration (OSHA), n.d.). As such, the evaluators agreed the system could not currently be incorporated into operations.

Additionally, two of three evaluators that donned the prototype noticed a sensor wire out of the corner of their right eye. While this did not obstruct their view, the fact they noticed the wire, in and of itself, would make the WiPEM system unacceptable for operations. Also, two of the three evaluators had difficulty viewing the GUI in broad day light, but did not have the same difficulty in low-light conditions.

Lastly, the evaluators recommended that the WiPEM system either turn on automatically when firefighters go on-air, or that the on/off switch be relocated to the outside of the SCBA to make it easier for the firefighter to turn the system on and off.

4.0 REFERENCES

Occupational Safety and Health Administration (OSHA). (n.d.). *Appendix A to § 1910.134: Fit Testing Procedures (Mandatory)*. Retrieved from U.S. Department of Labor, OSHA, Regulations (Standards - 29 CFR): www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9780

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